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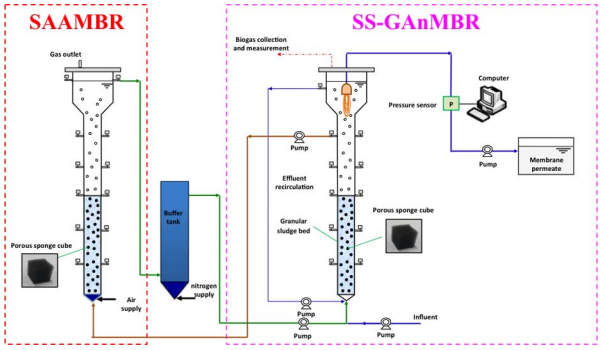
Effects of C/N ratio on the performance of a hybrid sponge-assisted aerobic moving bed-anaerobic granular membrane bioreactor for municipal wastewater treatment

C. Chen[a], W.S. Guo[a,*], H.H. Ngo[a], S.W. Chang[b], D.D. Nguyen[b,c], J. Zhang[d], S. Liang[d], J.B. Guo[e], X.B. Zhang[e]

[a] Centre for Technology in Water and Wastewater, School of Civil and Environmental Engineering, University of Technology Sydney, Sydney, NSW 2007, Australia
[b] Department of Environmental Energy & Engineering, Kyonggi University, 442-760, Republic of Korea
[c] Institute of Research and Development, Duy Tan University, Da Nang, Viet Nam
[d] Shandong Key Laboratory of Water Pollution Control and Resource Reuse, School of Environmental Science and Engineering, Shandong University, Jinan 250100, China
[e] Department of Environmental and Municipal Engineering, Tianjin Chengjian University, Jinjing Road 26, Tianjin 300384, China

GRAPHICAL ABSTRACT



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ABSTRACT

This study aimed to evaluate the impact of C/N ratio on the performance of a hybrid sponge-assisted aerobic moving bed-anaerobic granular membrane bioreactor (SAAMB-AnGMBR) in municipal wastewater treatment. The results showed that organic removal efficiencies were above 94% at all C/N conditions. Nutrient removal was over 91% at C/N ratio of 100/5 but was negatively affected when decreasing C/N ratio to 100/10. At lower C/N ratio (100/10), more noticeable membrane fouling was caused by aggravated cake formation and pore clogging, and accumulation of extracellular polymeric substances (EPS) in the mixed liquor and sludge cake as a result of deteriorated granular quality. Foulant analysis suggested significant difference existed in the foulant organic compositions under different C/N ratios, and humic substances were dominant when the fastest fouling rate was observed. The performance of the hybrid system was found to recover when gradually increasing C/N ratio from 100/10 to 100/5.

* Corresponding author.
E-mail address: wguo@uts.edu.au (W.S. Guo).

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1. Introduction

Granular anaerobic membrane bioreactors (G-AnMBRs) offer a promising opportunity to transform conventional municipal wastewater plants into net producers of renewable energy with significantly reduced sludge handling costs and energy demand while occupying a small footprint (Chen et al., 2017a). Owing to the competitive advantages of granular biomass, G-AnMBRs have gained particular interest for fouling mitigation since membrane fouling has remained as one of the most critical challenges, hindering the progress of conventional AnMBRs (C-AnMBRs), predominantly in the form of continuous stirred tank reactor configuration (Chen et al., 2017b). Martin-Garcia et al. (2011) successfully applied a G-AnMBR, and reported that the G-AnMBR had much slower fouling than the C-AnMBR because the G-AnMBR sludge had a lower mixed liquor suspended solids (MLSS) and 50% less of soluble microbial products (SMP) than those of the C-AnMBR. More fouling reduction in G-AnMBR due to the significantly reduced solid and colloidal loading (by a factor of 10 and 3, respectively) on the membrane was also reported in another study of Martin-Garcia et al. (2013).

Recent research has found that the incorporation of membrane into the granular systems could negatively affect the integrity of anaerobic granules and lead to severe membrane fouling, thus exacerbating the long-term performance of G-AnMBRs (Ozgun et al., 2015; Chen et al., 2017a). The low-cost polyutrethane sponge, an ideal attached growth mobile carrier, has been successfully applied in many aerobic membrane bioreactors (AMBRs) studies to enhance the overall performance of AMBRs due to its high internal porosity and specific surface area, high stability to hydrolyse and light weight (Guo et al., 2010). Chen et al. (2017a) worked on a sponge-assisted G-AnMBR (SG-AnMBR), and indicated that sponge addition into G-AnMBR could enhance organic and nutrient removal, and maintain superior granular quality. Additionally, sponge media could not only positively affect the concentration and properties of microbial products (e.g. SMP and extracellular polymeric substances (EPS)) in granular sludge, cake layer as well as settling zone mixed liquor, but also reduce fouling resistance by 50.7%, thereby alleviating membrane fouling.

Although studies have proved that the sponge addition could improve nutrient removal (Nguyen et al., 2011), nutrient removal efficiencies were still considered quite low in the SG-AnMBR (Chen et al., 2017a), limiting its universal appeal for municipal wastewater treatment (Smith et al., 2012). Additionally, adopting conventional biological nutrient removal technologies at the downstream of SG-AnMBRs was also not feasible since low C/N ratio in SG-AnMBR effluents inhibited denitrification and phosphorus removal processes due to insufficient organic electron donor presented. Thus, C/N ratio is one of the most influential parameters affecting nutrient removal process as it affects the population and biodiversity of functional microorganisms (Lin et al., 2016). Moreover, membrane fouling can be significantly influenced by C/N ratio because C/N ratio profoundly affects the physiological property of microorganisms and chemical composition of biomass, and influences the concentrations of EPS and SMP and their protein and polysaccharides contents (Hao et al., 2016).

In this study, a new hybrid sponge-assisted aerobic moving bed-anaerobic granular membrane bioreactor (SAAMB-AnGMBR) was developed to overcome the two major issues (i.e. fouling and low nutrient removal) impeding the progress of G-AnMBRs. Based on the literature, it is the first development of the hybrid configuration for enhancing nutrient removal and fouling control of G-AnMBR during municipal wastewater treatment. The main aim of this study was to evaluate the effects of C/N ratio on the performance of such a hybrid system in terms of pollutants removal (particularly for nutrient removal) and membrane fouling. The system recovery after the overloaded nitrogen event was also evaluated in the study.

2. Methods

2.1. Wastewater and sponge

The synthetic wastewater was prepared with glucose, ammonium sulphate, potassium dihydrogen orthophosphate together with trace metals to simulate municipal wastewater just after primary treatment, providing dissolved organic carbon (DOC) of 105–128 mg/L, chemical oxygen demand (COD) of 330–370 mg/L, orthophosphate (PO_4-P) of 3.0–3.5 mg/L, ammonia nitrogen (NH_4-N) of 12–15 mg/L, nitrite nitrogen (NO_2-N) of 0–0.02 mg/L and nitrate nitrogen (NO_3-N) of 0.2–0.8 mg/L. $NaHCO_3$ (powder, analytical grade) or 2 M H_2SO_4 was used to adjust pH to 7. Porous polyester-urethane sponge (PUS) cubes (dimensions: 2.5 mm × 2.5 mm × 2.5 mm), named S28-30/90R (density of 28–30 kg/m^3 with 90 cells per 25 mm) from Joyce Foam Products were used in the study.

2.2. Experimental set-up and operation conditions

The hybrid SAAMB-AnGMBR, consisting of a sponge-assisted aerobic moving bed reactor (SAAMBR) and a submerged sponge-assisted anaerobic granular membrane bioreactor (SS-AnGMBR), was continuously operated for 282 days in a temperature-controlled room (20 ± 0.5 °C). Each of the SAAMBR and the SS-AnGMBR had effective working volume of 3 L, and sponge fraction was 20% of working volume. At the bottom of the SAAMBR, fine bubble diffuser was set to supply air in order to provide complete liquid–solid mixing and moderate sponge up/down motion, and maintain dissolved oxygen (DO) concentration of 3.5–4.8 mg/L. Prior to continuous operation, the SAAMBR with fresh sponge was acclimatized to synthetic wastewater for 30 days at HRT of 12 h until the system reached relatively stable treatment performance. The attached growth on the sponge also reached steady state at 1.02 ± 0.04 g MLVSS/g sponge. The sponges and anaerobic granular sludge were acclimatised to synthetic wastewater for 30 days until a stable treatment performance was reached. The SS-AnGMBR was seeded with anaerobic granular sludge with initial MLSS concentration of 20.12 ± 1.21 g/L, and biomass grown on sponge cubes after acclimatization was 1.78 ± 0.09 g MLVSS/g sponge. A polyvinylidence (PVDF) hollow fiber membrane module with a pore size of 0.22 μm and surface area of 0.06 m^2 was immersed in the settling zone of the SS-AnGMBR.

The SS-AnGMBR was continuously fed with synthetic wastewater at a flow rate of 4.17 mL/min while wastewater from the SS-AnGMBR was continually transferred into the SAAMBR at the same flow rate. The SAAMBR effluent was recirculated back to the SS-AnGMBR through a nitrogen gas sparged buffer tank. The permeate pump in the SS-AnGMBR was operated in an intermittent mode with relaxation (8 min on and 2 min off) to acquire permeate from the membrane module with a constant filtration flux of 5.21 LMH. Both SAAMBR and SS-AnGMBR had HRT of 12 h, and upflow velocity in the SS-AnGMBR was maintained at 3.2 m/h using internal recirculation. The membrane fouling propensity was indicated by normalized trans-membrane pressure (TMP), which was recorded by a pressure transmitter. Operation was terminated when TMP exceeded 30 kPa, and fouled membrane was taken out for ex situ cleaning (Deng et al., 2016a).

The entire study period was divided in 2 phases according to the research objectives. In phase 1, the hybrid SAAMB-AnGMBR was fed with wastewater having C/N/P ratio = 100/5/1 (0–75 day), 100/6/1 (76–126 day), 100/8/1 (126–151 day) and 100/10/1 (151–166 day), respectively, with the aim to investigate the impact of C/N ratios on the performance of the hybrid system. In phase 2, after overloaded nitrogen events, the hybrid system was operated with C/N/P ratios of 100/6/1 (167–210 day) and then 100/5/1 (211–282 days) to investigate the extent of system recovery after the overloading nitrogen event.